Gas exchange

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:Intended learning objectives (ILOs)

:By the end of this lecture the student will be able to
.Define gas diffusion .1
Describe what is the partial pressure of a gas (PO_2& PCO_2 in .2
.the body)
List the factors affecting gas diffusion between alveolar air and .3
.capillary blood
.Describe the diffusing capacity of a gas .4
Compare between perfusion and diffusion limitations to gas .5
.exchange

:Sites of Gas exchange

.At the lungs: between pulmonary capillary blood & alveolar air*
At the tissues: between systemic capillary blood & *
.tissues

:Mechanism of Gas exchange

Simple passive diffusion i.e.down partial pressure gradient from high to low partial pressure

Gas Diffusion:

Definition:
Is a net movement of gas molecules from area of high concentration to area of low concentration.
Factors affecting:
1- Concentration gradient of the gas
2- Molecular weight of the gas
3- Solubility of the gas
4- Temperature
5- Surface area of the membrane
6- Thickness of the membrane

****Partial Pressures**
Atmospheric air is a mixture of gases; typical dry air contains about 79% nitrogen (N2) and 21% O2, with almost negligible percentages of CO2, H2O vapor, other gases, and pollutants. Altogether, these gases exert a total atmospheric pressure of 760 mm Hg at sea level. This total pressure is equal to the sum of the pressures that each gas in the mixture partially contributes. The pressure exerted by a particular gas is directly proportional to the percentage of that gas in the total air mixture. Every gas molecule, no matter what its size,

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exerts the same amount of pressure; for example, a N2 molecule exerts the same pressure as an O2 molecule. Because 79% of the air consists of N2 molecules, 79% of the 760 mm Hg atmospheric pressure, or 600 mm Hg, is exerted by the N2 molecules. Similarly, because O2 represents 21% of the atmosphere, 21% of the 760 mm Hg atmospheric pressure, or 160 mm Hg, is exerted by O2. The individual pressure exerted independently by a particular gas within a mixture of gases is known as its **partial pressure**, designated by *P*gas. Thus, the partial pressure of O2 in atmospheric air, ***P*O2**, is normally 160 mm Hg. The atmospheric partial pressure of CO2, ***P*CO2**, is negligible at 0.23 mm Hg. Gases dissolved in a liquid such as blood or another body fluid also exert a partial pressure. The greater the partial pressure of a gas in a liquid is, the more of that gas is dissolved.

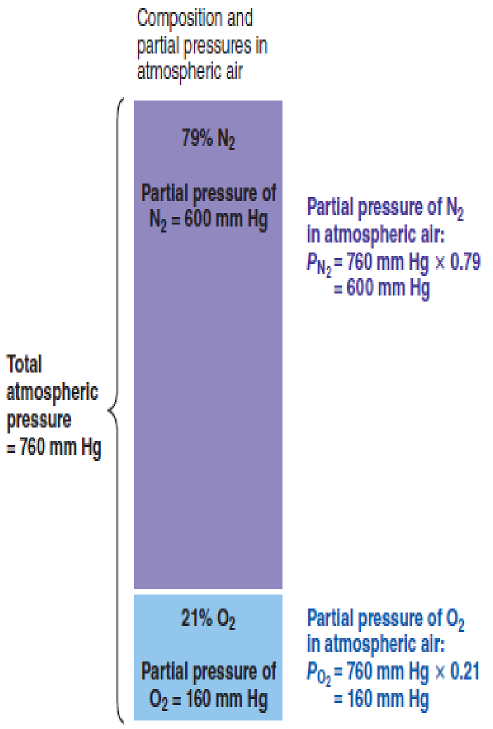
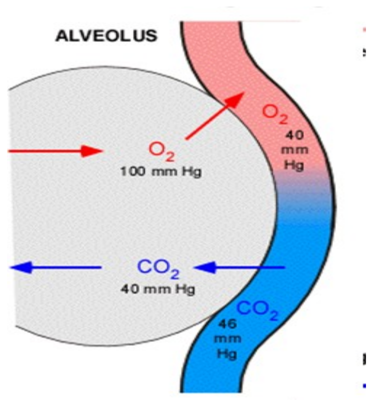


Figure 13-21 Concept of partial pressures. The partial pressure exerted by each gas in a mixture equals the total pressure times the fractional composition of the gas in the mixture.

Partial Pressure Gradients A difference in partial pressure between the capillary blood and the surrounding structures is known as a **partial pressure gradient**. Partial pressure gradients exist between the alveolar air and the pulmonary capillary blood. Similarly, partial pressure gradients exist between the systemic capillary blood and the surrounding tissues. A gas always diffuses down its partial pressure gradient from the area of higher partial pressure to the area of lower partial pressure, similar to diffusion down a concentration gradient.



Gas exchange in the lung

.Venous blood enters pulmonary capillaries (High PCO_2 & Low PO_2)-
.Air enters alveoli (High PO_2 & Low PCo_2)-
.→O_2 diffuses from alveoli to blood down its pressure gradient
.→CO_2 diffuses from blood to alveoli down its pressure gradient

:O_2 diffusion

Alveolar PO_2 of 100mmHg is higher than venous blood PO_2 of .40mmHg that enters the lung

This will create a partial pressure gradient of 60mmHg from .alveoli to blood

O_2 diffuses down its partial pressure gradient from alveoli to .blood until blood PO_2 becomes equal to alveolar PO_2

Therefore, blood leaving the pulmonary capillaries has PO_2 = .alveolar PO_2 = 100mmHg

:CO2 diffusion

Venous blood entering the pulmonary capillaries has PCO_2 of .46mmHg whichis higher than alveolar PCO_2 of 40mmHg

This will create a partial pressure gradient of 6mmHg from blood .to alveoli

CO_2 diffuses down its partial pressure gradient from blood to .alveoli until blood PCO_2 becomes equal to alveolar PCO_2

Therefore, blood leaving the pulmonary capillaries has PCO_2 = .alveolar PCO_2 = 40mmHg

*** The CO2 remaining in the blood even after passage through the lungs plays an important role in the** acid–base balance **of the body because CO2 generates carbonic acid. Furthermore, arterial *P*CO2 is important in** driving respiration**.**

Alveolar-Capillary membrane (Respiratory :membrane)

:In the lung, gas diffusion occurs through the alveolo-capillary membrane *

- ❑ 0.5 to 1 μm thick.
- ❑ Have a total surface area of about 70 m^2 (40 times that of one’s skin)
- ❑ Consists of the following layers:
  1) Fluid lining alveolus containing surfactant.
  2) Alveolar epithelium.
  3) Epithelial basement membrane.
  4) Interstitial space.
  5) Capillary basement membrane.
  6) Capillary endothelium.

Factors affecting gas diffusion across the alveolar-:capillary membrane

Partial pressure gradient of the gas across the -1 alveolar-capillary membrane: (60 mmHg for O_2 & 6 mmHg for .CO_2)
Surface area of the alveolar-capillary membrane: (about **-2** .70 m^2)
Thickness of the alveolar-capillary membrane: (about **-3**
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.) μ
- **4**
D i f f u s

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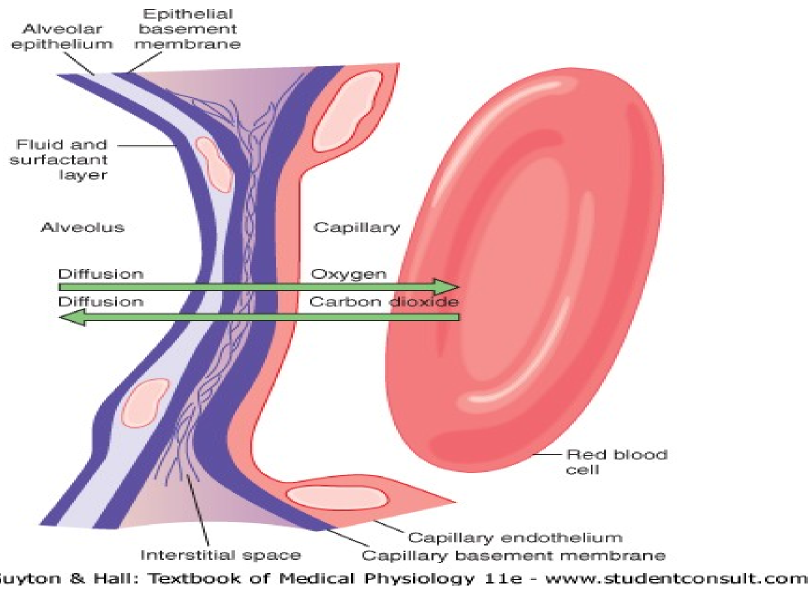

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:ent of the gas that depends on
.**Gas solubility:** (CO_2 is 24 times soluble than O_2)
Molecular weight of the gas: (CO_2 M.W. is 1.4 times greater .than O_2)

Rate of gas diffusion α

Diffusion coefficient X partial Pressure gradient x Surface area of the membrane

Thickness of the membrane

*The volume of gas transfer across the alveolar-capillary membrane per unit time is:
Directly proportional to:
- The difference in the partial pressure of gas between alveoli and capillary blood.
- The surface area of the membrane.
- The solubility of the gas.

Inversely proportional to:
- Thickness of the membrane.
- Molecular weight of the gas.

Solubility of the gas
Diffusion coefficient α
MW of the gas√

- ✓ Diffusion coefficient is directly proportional to solubility of the gas, and inversely proportional to the square root of gas's molecular weight (MW).
- ✓ Diffusion coefficient for CO2 is 20 times that of O2 because: CO2 is 24 times more soluble than O2 is, but the MW of CO2 is 1.4 times greater than that of O2.

N.B: In lung diseases that impair diffusion, O_2 diffusion is more seriously impaired than CO_2 diffusion because of the greater CO_2 diffusion .coefficient

The diffusion capacity of the respiratory membrane

- **Definition:**

The volume of gas that diffuses across the alveolar-capillary membrane / min for a pressure difference of 1 mmHg.

= 20 ml / min./ mmHg for O_2.

= 400 ml / min./ mmHg for CO_2.

- **Diffusion capacity increases during exercise:** This is due to:

- Opening of pulmonary capillaries → increase of surface area.
- Increased alveolar expansion by deeper breathing.

- **Diffusion capacity decreases in:**
  - ❑ Conditions that increases alveolar-capillary membrane thickness.
    e.g. lung fibrosis and pulmonary oedema.
  - ❑ Conditions that decreases the effective area for diffusion.
    e.g. collapse, emphysema.
  - ❑ Ventilation perfusion mismatch

Types of Gas Exchange: 2 types

- Diffusion-Limited Gas Exchange: applies to CO

- Perfusion-Limited Gas Exchange: applies to N_2O, CO_2

N.B:

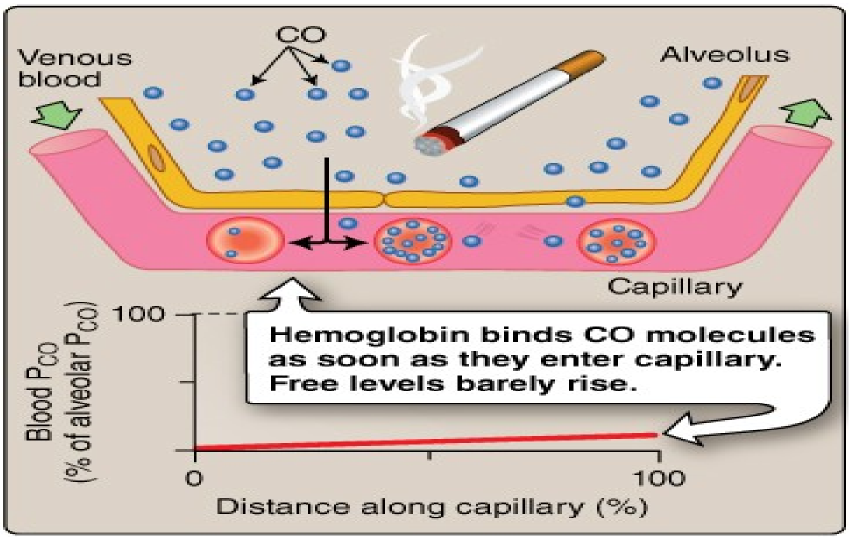
- The physically dissolved form of the gas is the form that determine its partial pressure.
- Net diffusion into pulmonary capillary depends on magnitude of partial pressure gradient.
- Whether a gas reaching equilibrium or not depends on its reaction with substances in the blood.
- 0.75 sec is the time the blood takes to traverse the pulmonary capillaries at rest.

1- Diffusion-Limited Gas Exchange: applies to CO

- Gas exchange across alveolar-capillary barrier is limited by diffusion process
- Net diffusion into pulmonary capillary depends on magnitude of partial pressure gradient.
- Example: CO
  - partial pressure of CO (PACO) in alveolar air is constant along length of capillary

- partial pressure of CO (PaCO) in capillary blood is zero at beginning of pulmonary capillary
- largest partial pressure gradient of CO and largest driving force for diffusion of CO from alveolar air into capillary blood at beginning of pulmonary capillary
- CO diffuses into capillary blood, PaCO rises only slightly along length of pulmonary capillary as:
  - CO avidly binds hemoglobin inside RBCs, maintaining a low PaCO (only the free, physically dissolved gas in capillary blood causes a partial pressure)

So, **CO does not equilibrate** by end of capillary regardless of the amount of blood flow, partial pressure gradient of CO is maintained along entire length of



capillary and this maintains driving force for net diffusion of CO.

Diffusion-Limited Gas Exchange

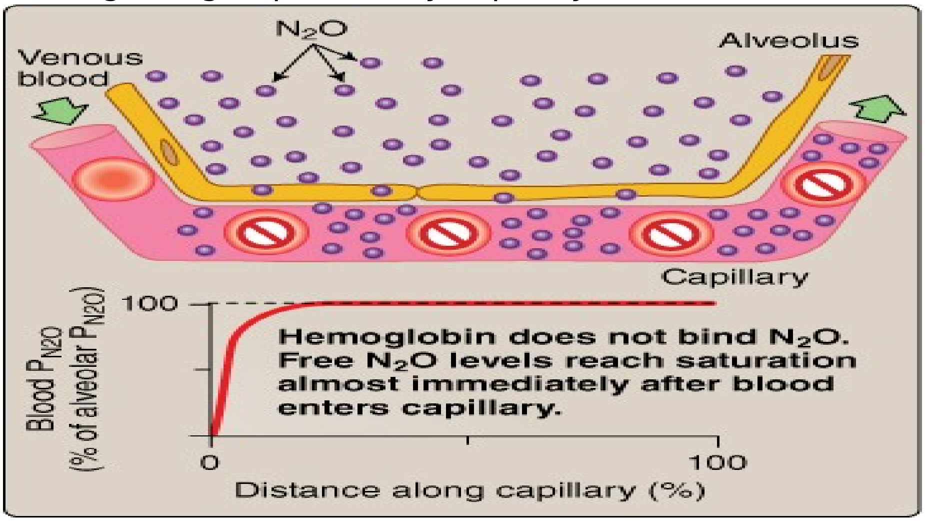
Perfusion-Limited Gas Exchange: applies to **-2**

N_2O, CO_2

■Gas exchange across alveolar-capillary barrier is limited by blood flow through pulmonary capillaries (perfusion)

■Example: N_2O

- partial pressure of N_2O (PAN_2O) in alveolar air is constant along length of capillary
- partial pressure of N_2O (PaN_2O) in capillary blood is zero at beginning of pulmonary capillary

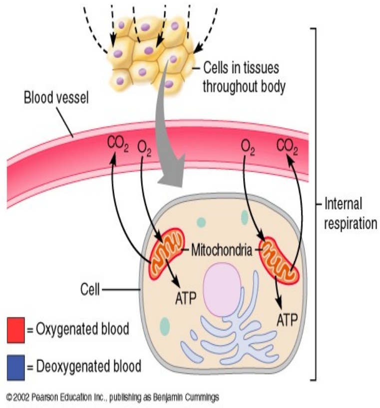


- largest partial pressure gradient of N_2O and largest driving force for diffusion of N_2O from alveolar air into capillary blood at beginning of pulmonary capillary
- N_2O diffuses into capillary blood, PaN_2O rises rapidly along length of pulmonary capillary as:
  - N_2O remains a free, dissolved gas in capillary blood.

  So, **N_2O equilibrates early** along length of capillary, partial pressure gradient of N_2O is not maintained along length of capillary, this eliminates the driving force for net diffusion of N_2O. And only means for increasing net diffusion of N_2O is by increasing blood flow through pulmonary capillaries (perfusion)

***O_2 is intermediate between N_2O and CO; it is taken up by hemoglobin, but much less avidly than CO, and it reaches equilibrium with capillary blood in about 0.3 sec. Thus, its uptake is **perfusion-limited.**

Perfusion-Limited Gas Exchange



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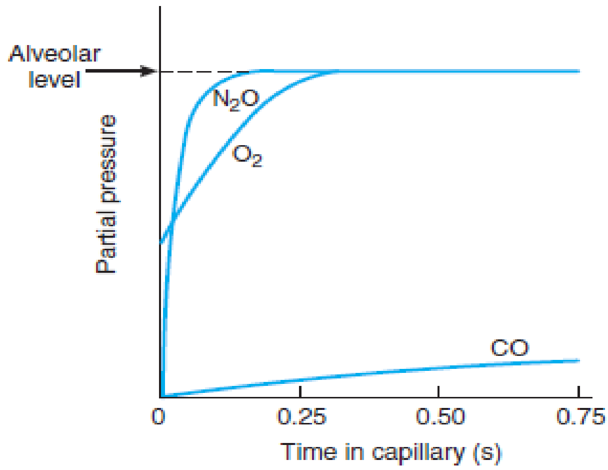
N2O is not bound in blood, so its partial pressure in blood rises-
.rapidly to its partial pressure in the alveoli
Conversely, CO is avidly taken up by red blood cells, so its partial-
.pressure reaches only a fraction of its partial pressure in the alveoli
.O2 is intermediate between the two-



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Gas Exchan Tissue

Across systemic

capillaries:

- O_2 partial pressure gradient of 60 mmHg from blood to tissue cells causes O_2 diffusion into the cells.
- CO_2 partial pressure gradient of 6 mmHg from tissue cells to blood causes CO_2 diffusion into the blood.

Lecture Quiz

- ✓ ***True or false?***

.O_2 and CO_2 have equal diffusion coefficients-1
PO_2 in blood entering the pulmonary capillaries is ˃PO_2 in the -2
.alveoli
PCO_2 in blood entering the pulmonary capillaries is ˂ PCO_2 in the -3
.alveoli
PO_2 in the alveoli is = PO_2 in blood leaving the pulmonary -4
.capillaries
PCO_2 in the alveoli is =PCO_2 in blood leaving the pulmonary -5
.capillaries
PO_2 in blood leaving the pulmonary capillaries is =PO_2 in blood -6
.entering the systemic capillaries
PCO_2 in blood leaving the pulmonary capillaries is ˃ PCO_2 in blood -7
.entering the systemic capillaries
PO_2 in blood entering the systemic capillaries is = PO_2 in the -8
.tissue cells
PCO_2 in blood entering the systemic capillaries is ˂PCO_2 in the -9
.tissue cells
PO_2 in the tissue cells is ˃ PO_2in blood leaving the systemic -10
.capillaries
PCO_2 in the tissue cells is = PCO_2 in blood leaving the systemic -11
.capillaries
PO_2 in blood leaving the systemic capillaries is ˂ PO_2 in blood -12
.entering the pulmonary capillaries
PCO_2 in blood leaving the systemic capillaries is ˂ PCO_2 in blood -13
.entering the pulmonary capillaries

- ✓ **Define *partial pressure of gas.***
- ✓ **What determines the partial pressures of a gas?**
- ✓ **Make a sketch showing the *P*O_2 and *P*CO_2 gradients and the direction of O_2 and CO_2 movement between the alveoli and pulmonary capillaries and between the tissue cells and systemic capillaries.**

SUGGESTED TEXTBOOKS

1. Ganong's review of medical physiology 25th edition
2. Lippincott's illustrated reviews: Physiology
3. BRS Physiology 6th ed.
4. Sherwood 9th edition